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Behaviour of the Beam to Column Connection for Tapered Steel Section with Perforation

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ABSTRACT

Connections are joints or nodes which are used to joint elements of a structure at a point such that forces can be transferred between them safely. Tapered steel section with perforation is normally used in construction industry due to light weight. The connection modelled in this research is extended end plate welded with tapered beam steel section with perforation and then bolted to UKC front flange of column. This connection was modelled by using Finite Element software, LUSAS to determine the moment rotation curve, deformed shape and maximum displacement of the connection. The results were compared between perforated and non-perforated sections. The dimension of the model sizes are 460 x 200 x 10 mm thickness of endplate, 457 x 191 x 82 UKB provided with 0.4h opening size and tapered ratio of 0.3 and 254 x 254 x 73 UKC. The Finite Element models were varied in terms of the distance from first opening to column's face and spacing between openings. The parameters of the openings affect the connection behaviour in a number of ways. It was found that when the distance between first opening and column face become longer, the effect of openings is eliminated. Moreover, tapered steel beam section with perforation has less moment resistance value than tapered steel beam section without perforation as much as 4.34% to 9.70%.

1. Introduction

Connections are joints or nodes which are used to joint elements of a structure at a point such that forces can be transferred between them safely. The mechanical properties of the connections have a great influence on strength and stability of the whole structure. If the design of the connections is not considered, it can diminish the serviceability of the structure because of large deflection. Moment rotation curve is a graph that describes the relationship between bending moment, Mj applied to a joint and the corresponding rotation, Φj between connected members. It is one of the ways to represent joint behaviour [2]. The joint behaviour characteristics are the moment resistance, MR and rotational stiffness, k. It depends on size and number of bolts, end plate thickness and and configuration detail [5]. Fig. 1 shows some example moment rotation curve of beam to column connection.

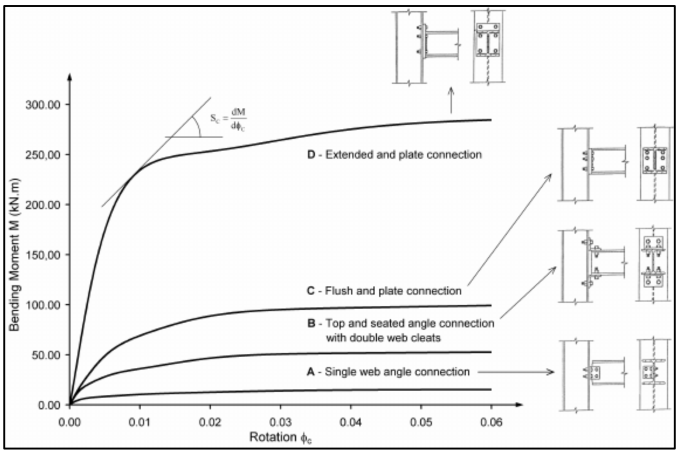


Fig. 1 Moment rotation curve of beam to column connection [7]

Deformed shape is one type of failure occur in extended end plate connection. It occurs due to bending of the end plate, deformation of bolts and bending of beam flange. The deformations are the combination between local buckling happened at top flange [11]. Fig. 2 shows an example deformed shape of extended end plate connection. Omar (2012) done studied on beam to column connection for triangular web profiled by using LUSAS software. Flush end plate connection was chosen in this study. The results were compared with existing flush end plate connection for normal flat web. From that study, the triangular web profiled has more strength and higher stiffness than normal flat web. The triangular web profiled also has less value on moment resistance but higher ultimate moment compared to normal flat web.

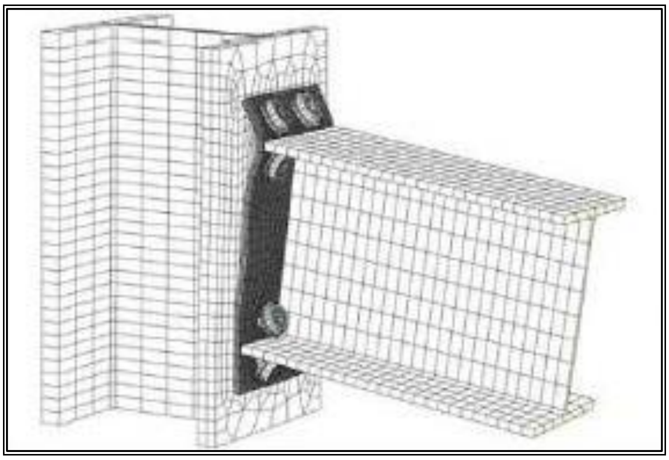


Fig. 2 Deformed shape of extended end plate connection [8]

Vahid et al. (2013) have done studied on beam to column connection using castellated beam under monotonic and cyclic loading. LUSAS was used as tool for this research. Four finite element models which only one of them has 4 opening while others have three openings. The parameters in this research are spacing between openings, opening sizes number of openings. The opening is hexagonal shape. From the results, it shows that models with the same opening size, the load capacity increases as the spacing between openings increase.

Tsavdaridis et al. (2014) done studied on beam to column connection using perforated section subjected to cyclic loading. Flush end plate was chosen in this study. The parameters in this study are the effects of opening depth, distance of first opening to column's face. It was found that, all the parameter affected the connection's behaviour in a different way. For example, the variation of opening depth has the highest impact on the connection's strength and rotational ductility. Whereas, the distance of first opening to column face has the lowest impact on connection's strength and rotational ductility. Model with large opening has better strength and ductility when it is located further away from column face because the stress concentration is high at the welded region. For model with small opening, the effect of opening was eliminated when it is located further away from column face.

Potentially weak areas may occur in the beam to column connection the areas such as column flange and column web. The mechanical properties of the connections have a great influence on strength and stability of the whole structure. There have been many researches in the past regarding beam to column connection but none of them used tapered steel beam section with perforation. Finite Element Analysis using LUSAS software was conducted in this analysis to determine moment rotation curve of extended end plate connection for tapered steel section with perforation and to determine deformed shape and maximum displacement of extended end plate connection for tapered steel section with perforation.

2. Finite Element Modelling

In this research, extended end plate connection was analysed using finite element analysis method. LUSAS Finite Element software was chosen in this study to analyse the behaviour of extended end plate connection in two different beam profiles that are tapered beam with and without perforation. Then, these two beam profiles were compared. These models were designed according to Eurocode 3 [3]. The most common grade of steel used in designed was S275 steel. The purpose of this study was to recognize rotational behaviour from the mechanism bolted end plate beam to column connection, column flange and end plate bending deformations and beam deformations within the connecting zone.

Different opening arrangement on the beam web were investigated by analysing 10 models as shown in Table 2. Nine models are prepared with perforation on the beam web while the other one was modelled without perforation The opening arrangement were the distance between first web opening and column's face, S1 and the spacing between web openings, S2. One of the models was tapered beam without perforation while the others were tapered beam with perforation. All the models were compared in order to determine the relationship between moment rotation curve, deformed shape and maximum displacement of the connections. Refer to Fig. 3 for illustration of extended end plate connection model. Table 1 shows the parameters that were fixed for connection modelled between beam and column.

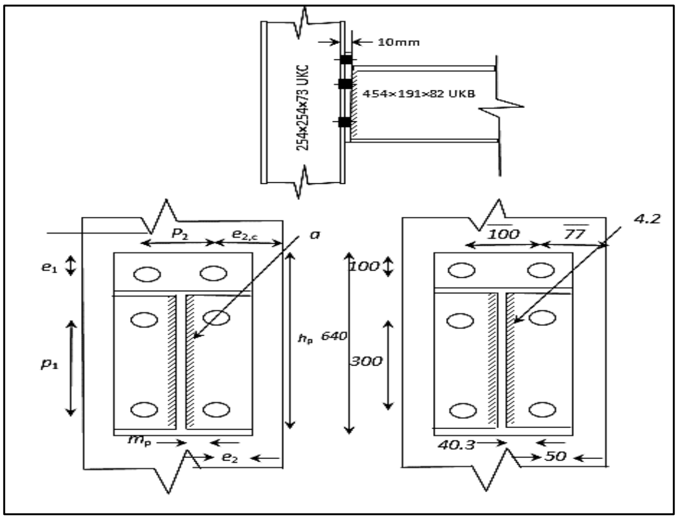
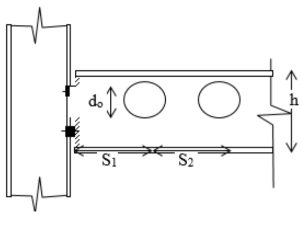


Fig. 3 The arrangement and dimension of extended end plate connection model

Table 1 Fixed joint Configuration

Member	Section	Web thickness (mm)	Flange thickness (mm)	Plate thickness (mm)	Tapered Ratio	Opening Dimension
Column	254 x 254 x 73 UKC	8.6	14.2	-	-	-
Beam	457 x 191 x 82 UKB	9.9		-	0.3	0.4h
End Plate	640 x 200	-	-	10	-	-

The difference between the nine finite element models were the distance between first web opening and column's face, S2 and spacing between web openings, S1. Refer to Fig. 4 for illustration of do, S1 and S2. Each model was represented with a specific three field identifier as shown in Fig. 5. For instance, P1-400 is the perforated beam section with spacing between openings, S2 of 0.87h and location of first opening 400 mm away from column's face. Table 2 shows the manipulated parameter for all models.



d_o = depth of web opening

S_1 = Distance between first web opening and column's face,

S_2= Spacing between web openings

h = web depth

Fig. 4 Geometric parameter of d_o, S_1 and S_2

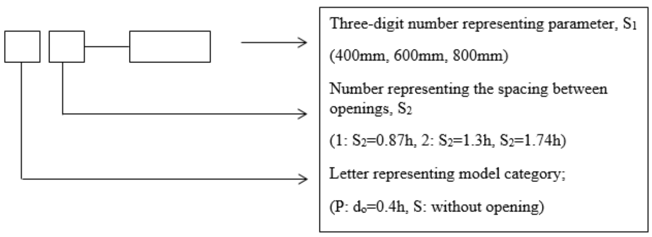


Fig. 5 Model classification

Table 2 Values of S_1 and S_2 for models

Model	Spacing between web openings, S_2	Distance between first web opening and column's face, S_1
S	-	-
P1-400	0.87h	400
P1-600	0.87h	600
P1-800	0.87h	800
P2-400	1.3h	400
P2-600	1.3h	600
P2-800	1.3h	800
P3-400	1.74h	400
P3-600	1.74h	600
P3-800	1.74h	800

Six numbers of M20 bolts of grade 8.8 were used in this model. All the dimensions and parameters of connection, and modelling process were made exactly as possible to the model from previous research [6]. Element type's 3D continuum element (HX8M), thick shell element (QTS4), joint element (JNT4) and bar element (BRS2). These types of element were used in the modelling connection and were adopted from the model studied by (Butterworth, 1999). In order, to determine vertical and horizontal displacement, A point load of 10 kN was applied as reference load at the location 3510 mm from column face. By applying 10 kN of load, the load factor was increased from 1.0 to 50.0 in order to accomplish the necessary range of the connection bending moments in the nonlinear analysis.

Moment-Rotation (*M-Φ*) curve was not directly given from LUSAS analysis. The displacement and moment values at Node A and B (refer Fig. 6) were obtained from analysis with the corresponding to the increment of load factor. This displacement value at Node B was used to calculate the value of rotation by using Equation 1. Point A was located at the centre of column web, while point B was located at the neutral axis of the beam with a horizontal distance of *d* from node A as shown in Fig. 6.

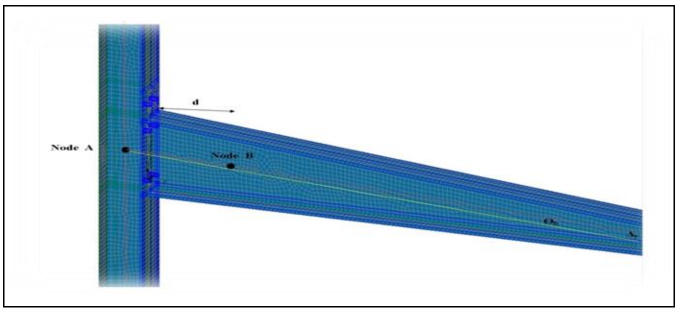


Fig. 6 Location for Node A, Node B

The procedures for manual calculations as follows:

$\Phi = \tan^{-1}(y/(x+d))$ Eqn. 1

$y = |YB - YA|$ Eqn. 2

$x = |XB - XB|$ Eqn. 3

M = Total load factor × P × L Eqn. 4

d = horizontal distance between node A and B
y = total vertical displacement (mm)
x = total horizontal displacement (mm)
YB = Vertical displacement of node B (mm)
YA = Vertical displacement of node A (mm)
XB = Horizontal displacement of node B (mm)
XA = Horizontal displacement of node A (mm)
M = applied moment (kNm)
P = applied load (kN)
L= distance applied load acting from column face (m)

3. Results and Discussion

Moment-rotation curves for all models were plotted using analytical results obtained from finite element analysis. Fig. 8 shows the moment rotation of non-perforated section has more strength than perforated sections. This was because non-perforated able to bear higher moment with small rotation compared to non-perforated sections. Table 3 shows the values of moment resistance and rotational stiffness for all models. Among the perforated sections, the best model was P2-800 because the value of moment resistance was the highest at 115 kNm.

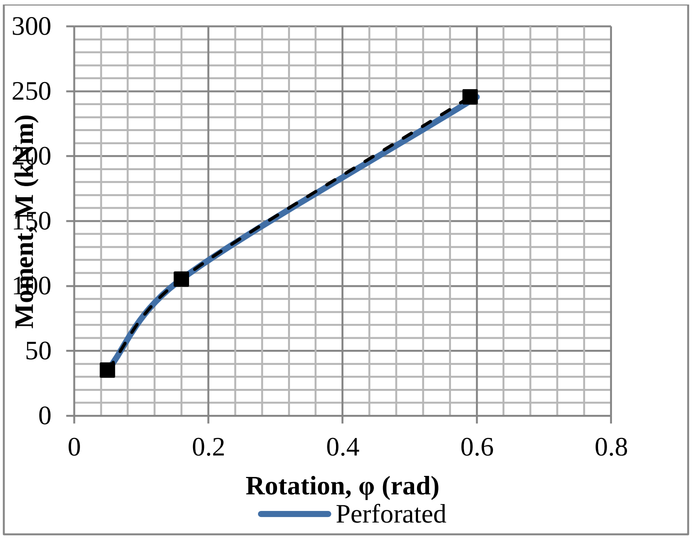


Fig. 8 Moment-Rotation curve for Perforated and Non-Perforated Sections

Table 3 Moment Resistance and Rotation Stiffness of all models

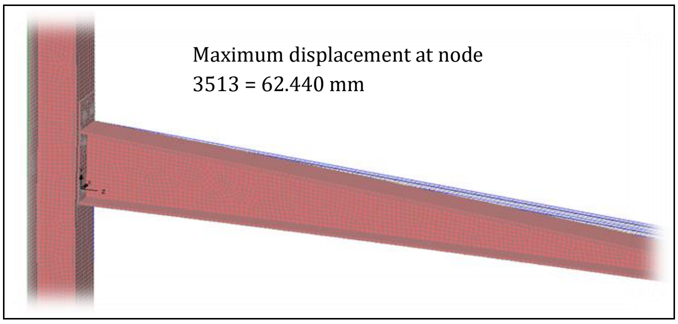
Model	Moment Resistance, M_R (kNm)	Rotational Stiffness, K (kNm/rad)
P1-400	100	588.24
P1-600	105	600.00
P1-800	110	611.11
P2-400	105	600.00
P2-600	110	611.11
P2-800	115	621.62
P3-400	105	600.00
P3-600	100	588.24
P3-800	95	575.76

S	120	631.58

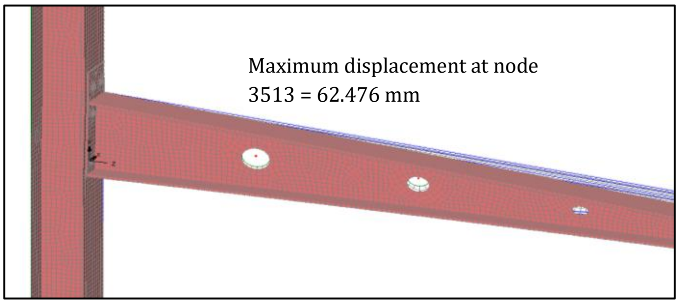
Table 4 shows the values of maximum displacement for all models. According to the Table, the values of maximum displacement between perforated sections were compared. Among the sections, the best models were P1-800, P2-400, P2-600, P3-400, P3-600 and P3-800 because the values of maximum displacement were closest to the value of non-perforated section in the range of 62 mm to 63 mm. Deformed shape and maximum displacement for all models were plotted using analytical results obtained from finite element analysis. Fig. 9 shows deformed shape of non-perforated section and the maximum lowest displacement for perforated section.

Table 4 Maximum Displacement for all models

Model	Maximum Displacement (mm)
P1-400	270.867
P1-600	207.034
P1-800	62.500
P2-400	62.499
P2-600	63.809
P2-800	104.519
P3-400	62.490
P3-600	62.844
P3-800	62.476
S	62.440



(a)



(b)

Fig. 9 Deformed shape of (a) model S for non-perforated section and (b) P3-800 for perforated section

4. Conclusion

The behaviour of the connection was found to be depends on the arrangement of openings on the beam such as the distance between first opening and column and the spacing between openings. From this study, the effects of web openings have been shown to contribute significantly to moment resistance and rotational stiffness of the connections. For example, for models with 0.87h of spacing between openings the higher the distance between first opening and column face the bigger the moment resistance and rotational stiffness. However, for models with 1.74h of spacing between openings, the higher the distance between first opening and column face the smaller the moment resistance and rotational stiffness. In terms of maximum displacement, the higher the distance between first opening and column face the smaller maximum displacement. However, for models with 1.74h of spacing between openings, the higher the distance between first opening and column face the maximum displacement remains constant. The best model was P2-800 because the value of moment resistance was the highest at 115 kNm. In addition, the best models were P1-800, P2-400, P2-600, P3-400, P3-600 and P3-800 because the values of maximum displacement were the lowest at 63 mm.

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